RECONCILIATION OF MAGNETIC AND PETROGRAPHIC CONSTRAINTS ON ALH84001? PANSPERMIA LIVES ON! B. P. Weiss[1], J. L. Kirschvink[1], F. J. Baudenbacher[2], H. Vali[3], N. T. Peters[2], F. A. Macdonald[1], and J. P. Wikswo[2], [1]Division of Geological and Planetary Sciences, 150-21, California Institute of Technology, Pasadena, California 91125, USA, [2]Department of Physics and Astronomy, Vanderbilt University, 6301 Stevenson Center, Nashville, TN 37235, USA, [3]McGill University, Montreal, Quebec, Canada

Introduction: ALH84001 has been the focus of controversy due to the hypothesis of McKay et al. [1] that the 20-200 μm carbonate globules deposited on its fracture surfaces contain evidence of early life on Mars. This interpretation implies that the carbonates formed at low temperature, but the thermal history of this meteorite has been controversial. Treiman [2] has argued that ALH84001 experienced two significant thermal metamorphic events prior to the deposition of the carbonate but after his D1 brecciation, based on the textures of granular bands, the homogeneity of the mineral composition of the entire rock, and the presence of feldspathic glass. Peak temperatures for this event, based on a variety of mineral thermometers, range between 800° and 1200° C [3].

In contrast, Kirschvink et al. [4] placed an upper limit of 110° C since the D1 brecciation event(s). Their conclusion was based on the study of the natural remanent magnetization (NRM) and magnetic properties of two adjacent pyroxenite grains which differed in the directions of their magnetizations by ~70°. We report here results from a new technology, scanning SQUID microscopy, which lowers this temperature constraint to a maximum of 40 ºC and helps constrain the petrologic history.

Magnetic Images of ALH84001: Figure 1 shows magnetic scans of 2 oriented ~1.5 mm-thick slices of ALH84001 numbered 232c and 232d. These slices were adjacent in the meteorite (one directly on top of the other) and taken from the meteorite's interior. Both slices are heterogeneously magnetized. In some places dipolar features are centered on fractures. Other fractures form the boundary between grains magnetized in different directions. The latter has been previously observed in a different study of individual ALH84001 grains [4].

Using the same technique, we made multiple magnetic images of ALH84001 slice 232e, which was extracted from immediately below 232d. The first image of the natural remanent magnetization (NRM) at room temperature was taken without having heated the sample. A heterogeneous pattern of magnetization was once again observed [5]. The sample was then heated to 40°C for 20 minutes in a magnetically shielded furnace and cooled in a zero field (< 10 nT). Even at temperatures as low as 40 °C, the magnitude of many features decreased significantly, completely erasing some that are present in the NRM scan. This implies that this rock has not been heated even to 40 °C since before the brecciation event which produced the heterogeneous pattern of magnetization.

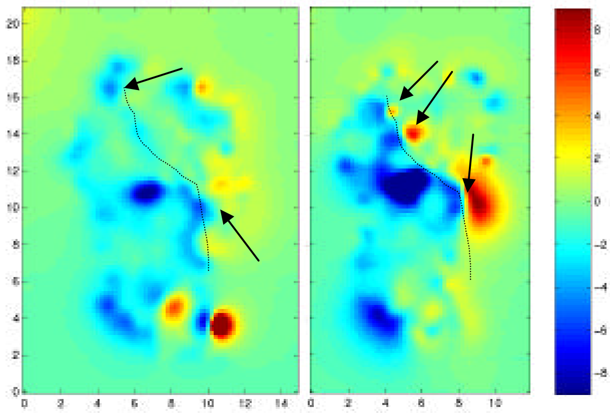

Figure 1. *Out-of-the-page component of the magnetic field of ALH84001-232c (left) and -232d (right) as observed ~200 um above the slices. Tick marks are 2 mm, colorbar is in nT. Red (blue) regions are upwardly (downwardly) magnetized. The same prominent crack (dashed line) runs from the upper left to the lower right through each slice. This crack continues into 232e (see Figure 2). Several strong dipolar features (labeled with arrows) magnetized in the same direction sit on and trace this fracture.*

Thermal demagnetization of sample 232e was continued in 10 °C steps up to 200 °C. It was then heated to 360 °C in a zero-field vacuum for 10 min to completely demagnetize the pyrrhotite, leaving only the residual magnetization from minerals with higher Neél temperatures (e.g., magnetite). A close-up of the top half of the slice after heating to 360 °C is shown in Fig. 2a. The largest of these residual dipoles are centered on easily visible fracture surfaces, but are not associated with chromite stringers which trace the D1 granular bands (Fig. 2b). This suggests that this resistant magnetization is likely the signature of the magnetite in carbonate which is sitting in the wavy fracture running down the center of Fig 3b. We are currently drilling into this fracture to see if indeed there is magnetite present inside. Note, however, that as for the low-temperature scans, a few fractures define the boundary between differently magnetized regions rather than serve as hosts for dipoles (circled grain in Fig 2a).

Interpretation: Following Treiman's petrographic history [2], the dashed fractures are likely to

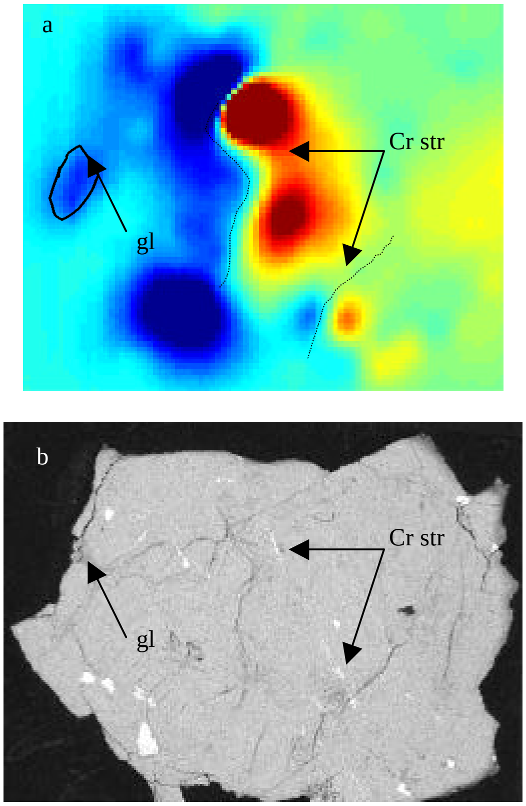

Figure 2. Images of top half of ALH84001-232e. Both images ~9 mm across. (a) Magnetic image after heating to 360 °C, showing location of magnetite. Fracture surfaces on which 2 dipole features sit labeled with dashed lines. Fracture defining a distinctly magnetized grain is labeled with a solid line. The upper left dashed fracture is the same one running through 232c and 232d (Fig 1) (b) Backscattered SEM image showing fractures (dark black lines), pyroxene (light grey), glass (dark grey, labeled "gl"), and chromite (white). Chromite stringers which trace D1 granular bands labeled "Cr str". Fractures labled in part (a) are visible.

be from his D2b deformation event, which followed the formation of the granular bands but preceeded carbonate formation. This is because this fracture is younger than the granular bands (it cuts across them). This is consistent with Treiman's proposed scheme in which the D2 deformation was preceded by several high temperature metamorphic and deformational events (D1, Cγ, and D2a). We see here that the many of the D1 granular bands themselves (traced partly by chromite stringers, Fig. 2) appear homogeneously magnetized, which is what one would expect if these regions were heated up above the blocking temperature of their component minerals (~325 °C for pyrrhotite).

However, there are two ways in which this interpretation conflicts with Treiman's history. First, the fact that some fractures separate grains magnetized in different directions suggests that there was rotation of grains during D2b. Treiman does not mention any evidence for such rotation. Second, Treiman argues that there was a high-temperature event (D3) which followed D2b. The main evidence for this D3 event is the presence of amorphous, relatively unfractured, silica-rich glass which was interpreted originally to be shock-melted feldspar (maskelynite) [2, 6]. One might expect that such an event would have homogenized the magnetization pattern observed here. However, amorphous silicic glass commonly forms as a trapped intercumulus melt at the end of igneous crystallization and settling, as has been observed in Chassigny [7] and the shergottites [8]. Flow of this glass during the subsequent 4 Gyr due to low-temperature tectonic or impact disturbances might account for the ~10 μm scale of these textures without invoking a post-D2 high-temperature event. It is also questionable whether the carbonate could survive a high-temperature event like D3.

Implications: If our interpretation is correct, then several important conclusions can be drawn from these data. First, the heterogeneous nature of the NRM magnetic patterns, with clearly expressed dipole features, confirms the earlier conclusion of Kirschvink et al. [4] that the sample is a low-temperature magnetic conglomerate. It also follows that no other event in the history of the rock subsequent to D2 has heated it to this level. Moreover, as the precipitation of the carbonate blebs (event Cγ of Treiman [2]) postdates the D2 deformation, they also probably formed at temperatures below 40 °C.

It is fairly certain that this heterogeneous pattern of magnetization was emplaced prior to the meteorite's ejection from Mars. This indicates that the ALH84001 was transferred from Mars to Earth without being heated above 40 °C. Thus, major impact events are capable of moving rocks from Mars to the surface of Earth without subjecting them to temperatures high enough to cause thermal sterilization. This lends strong support to the 150-year old hypothesis of panspermia that life could be transferred from Mars to Earth via meteorites.

References: [1] McKay, D., *et al.*, *Science*, 1996. **273**: p. 924-930, [2] Treiman, A.H.,. *Meteoritics*, 1998. **33**: p. 753-764, [3] Treiman, A.H., *Meteoritics*, 1995. **30**: p. 294-302, [4] Kirschvink, J.L., et al., *Science*, 1997. **275**: p. 1629-1633, [5] Weiss, B.P.et.al., 5th Intl. Mars. Conf. Abstr 6204, 1999, [6] Mittlefehldt, D.W., *ALH84001*, *Meteoritics*, 1994. **29**: p. 214-221, [7] Floran, R.J., *et al.*, *Geochim. et Cosmochim. Acta*, 1978. **42**: p. 1213-1230, [8] Stolper, E. and H.Y. McSween, *Geochim. et Cosmochim. Acta*, 1979. **43**: p. 1475-1498.